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GTEX: An Expert System for Diagnosing Faults in Satellite Ground Stations

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Abstract

A research effort was undertaken to investigate how expert system technology could be applied to a satellite communications system. The focus of the expert system is the satellite ground stations. Diagnostic procedures associated with the ground stations are very demanding. Knowledge about the operational characteristics, communications strategies and the associated electronics of the ground station is required.

A proof of concept expert system called GTEX (Ground Terminal Expert) was developed at The University of Akron in collaboration with NASA Lewis Research Center. The objective of GTEX is to aid in diagnosing data faults occurring with a digital ground terminal. Thou, research focused on large systems, this strategy can also be applied to the Very Small Aperture Terminal(VSAT) technology. An expert system which detects and diagnoses faults would enhance the performance of the VSAT by improving reliability and reducing maintenance time.

GTEX is capable of detecting faults, isolating the cause and recommending appropriate actions. Isolation of faults is completed to board-level modules. A graphical user interface provides control and a medium where data can be requested and cryptic information logically displayed. Interaction with GTEX consists of user responses and input from data files. The use of data files provides a method of simulating dynamic interaction between the digital ground terminal and the expert system. GTEX as described is capable of both improving reliability and reducing the time required for necessary maintenance.

GTEX was developed on a personal computer using the Automated Reasoning Tool for Information Management (ART-IM) developed by Inference Corporation. Developed for Phase II digital ground terminal, GTEX is a part of the Systems Integration Test and Evaluation(SITE) facility located at NASA Lewis Research Center.

1.0 Introduction

System studies performed during the late 1970's indicated that advanced communications satellite technologies should be developed to utilize the Ka-band (30/20 GHz) spectrum. In order to demonstrate Ka-band satellite communications systems, NASA Lewis Research Center has conducted an advanced space communications program. This program will meet the needs of future NASA missions and will infuse advanced technologies into the commercial sector. One objective of the program is to apply advanced digital logic to space communications including the satellite ground terminal and network control. The program focuses on several major areas: advanced modulation and coding; space based processing and control; and ground based processing and control. The goal of ground based processing and control focus is to develop cost efficient terminals. Expert systems are being applied to diagnose ground terminal failures and provide autonomous operation.

2.0 Background

Extensive development of satellite communications is currently under way at the NASA Lewis Research Center. Using proof-of-concept subsystems and components, (IF switch matrices, solid-state amplifiers, traveling-wave tube, high-power amplifiers and low-noise receivers) a Ka-band satellite communications network simulation known as the Satellite Integration, Test and Evaluation (SITE) facility has been developed. This facility allows modulated data to be used to characterize the effect of microwave components on Bit Error Rate (BER) performance and SITE supports voice, data, and video through a Time Division Multiple Access (TDMA) burst terminal and a three ground terminal network.

The ground terminal is a major element of the simulator and one of the more complex. Each ground terminal must be capable of acquiring satellite and network timing, maintaining synchronization to the network, and transmitting and receiving bursted data from other ground terminals in the network.

Each ground terminal, shown in Figure 1,contains a 221.184-MHz system clock, transmission and reception timing and control circuits, compression or expansion first-in, first-out memories (FIFO) separate user clocks and their associated control circuits, an orderwire processor microcomputer, a user interface controller, and a 221.184-MHz serial minimum-shift key(SMSK) burst modulator/demodulator (modem) (Ivanic, et al. 1989).

In the SITE ground terminal, users are simulated by a bit-error-rate test set consisting of a data generator (transmitting user) and a data checker (receiving user). A controlling computer creates realistic traffic patterns with users of varying data rates entering and leaving the system. The raido frequency (RF) components and links of the communication system can degrade the user's data which often results in bit errors. The users need to know the degree of data degradation to determine whether to tolerate it or compensate for it. Data degradation can be quantified by using a bit-error-rate (BER) figure. A BER provides a performance measure of the RF communication links, the RF and digital subsystems, and the overall satellite communication system.

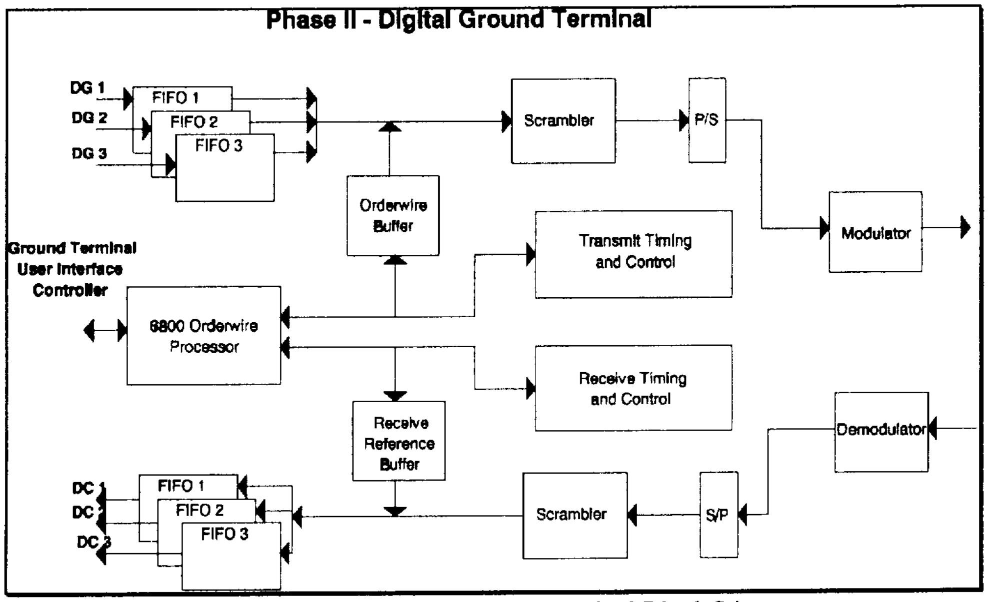

Figure 1. - SITE Digital Ground Terminal Block Diagram

Providing an interface to the users, the SITE ground terminals control the timing and the paths of the users' data transmission. Presently, each of the SITE ground terminals is capable of interfacing to three transmitting and three receiving users. The transmitting ground terminal multiplexes the data it receives from each transmitting user and bursts the data to the satellite at a high data rate. The receiving ground terminal receives the high-bursts and demultiplexes them so that each receiving user gets the proper data. (Shalkhauser 1988)

Since the SITE digital ground terminal is itself a prototype, new errors frequently occur. This required the scope of GTEX to be very concentrated. The errors associated with the transmitting and receiving of user data is the primary focus of GTEX.

Being developed as a diagnostic aid, GTEX will be used as a demonstrational prototype showing the feasibility of applying expert system technology in the area of high-rate digital communications at NASA Lewis Research Center.

4.0 Development Environment

GTEX is being developed using the Automated Reasoning Tool for Information Management (ART-IM) by Inference Corporation. ART-IM is a C-based toolkit for the development of rule-based, or knowledge-based, expert systems (ART-IM 1991). GTEX was developed on a low-cost development and deployment environment a personal computer(PC) running MS-DOS.

ART-IM supports three methods of programming styles; procedural, ruled-based and object-oriented. The procedural language supported by ART-IM provides basic function calls, and allows simple interactions and conditionals to be performed. The rule-based structure uses the rule as the fundamental unit. Reacting to changes in the working memory, the rule can then fire or execute based on the dynamic order of the changes which occur. Objects in ART-IM are represented by a schema. Control of an object is managed by sending a message to that object. An object reacts to a message by searching itself for an appropriate method and executing the actions associated with that method.

The ART-IM procedural language can be extended using the 'C' programming language. User functions can be written in C and included with the ART-IM program which can be used like any other ART-IM function. Since functions defined in C are complied versus interpreted, the result is faster execution. This capability of ART-IM was fundamental in the development of the user-interface discussed in this paper.

5.0 System Overview

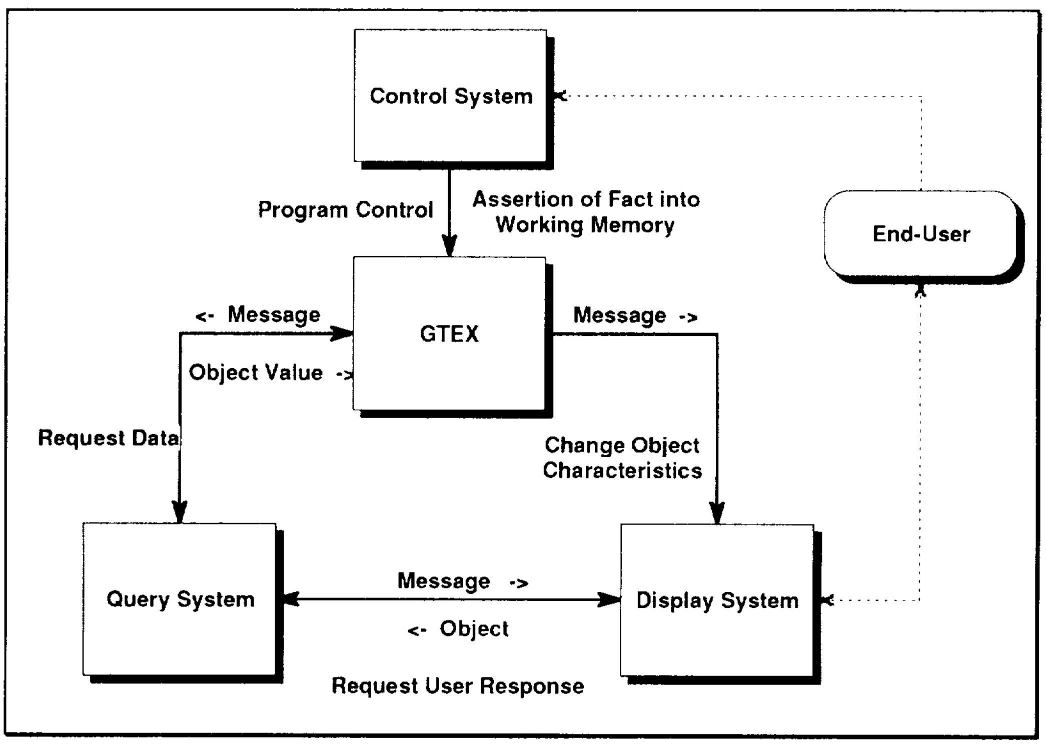

Figure 2. - GTEX Architecture

The GTEX architecture is divided into the following subsystems:

- Display subsystem
- Control subsystem
- Query subsystem
- Knowledge base

A modular approach was beneficial in system development. An extended ART-IM function was constructed for communications between the knowledge base, display and query subsystems. This implementation allows communications to be established from both ART-IM and C. Syntax would be as follows:

calling from ART-IM:

(send-message *system* "message")

calling from C:

```
aofnSendMessage(a_art_symbol(sSystemType), a_art_string(sMessage));
```

Communications with the knowledge base are achieved by asserting a fact into working memory corresponding to the end-users action. Messages each subsystem handles will be described in detail in the designated subsection.

The block diagram of the GTEX system architecture is shown in Figure 2. The diagram shows each subsystem and the possible communications paths.

5.1 Display Subsystem

A graphical environment was chosen to provide a dynamic interface. The GTEX interface shown in Figure 3 is capable of displaying dynamic system block diagrams, system status, and provide interactive dialog with the end-user. Dynamic system diagrams alert the end-user to changing conditions of the simulated digital ground terminal operation. Detailed diagrams of individual subsystems within the SITE ground terminal can also be displayed. Diagnostic messages regarding the inferencing process are conveyed to the end-user. Interactive dialog, implemented as a pop-up window, is provided to query information and provide a medium to display important messages.

The display subsystem receives a message string from either the knowledge base or query subsystem. The message string is in the form:

"Message-Type Message-Action"

Table 1, enumerates the message string possibilities.

Message Type	Message Action
Display	Page-Title
Update	Object
Initialize	-
Warning	Warning Message
Message	Message Number
Dialog	Object & Property

Table 1 - Message strings for Display Subsystem

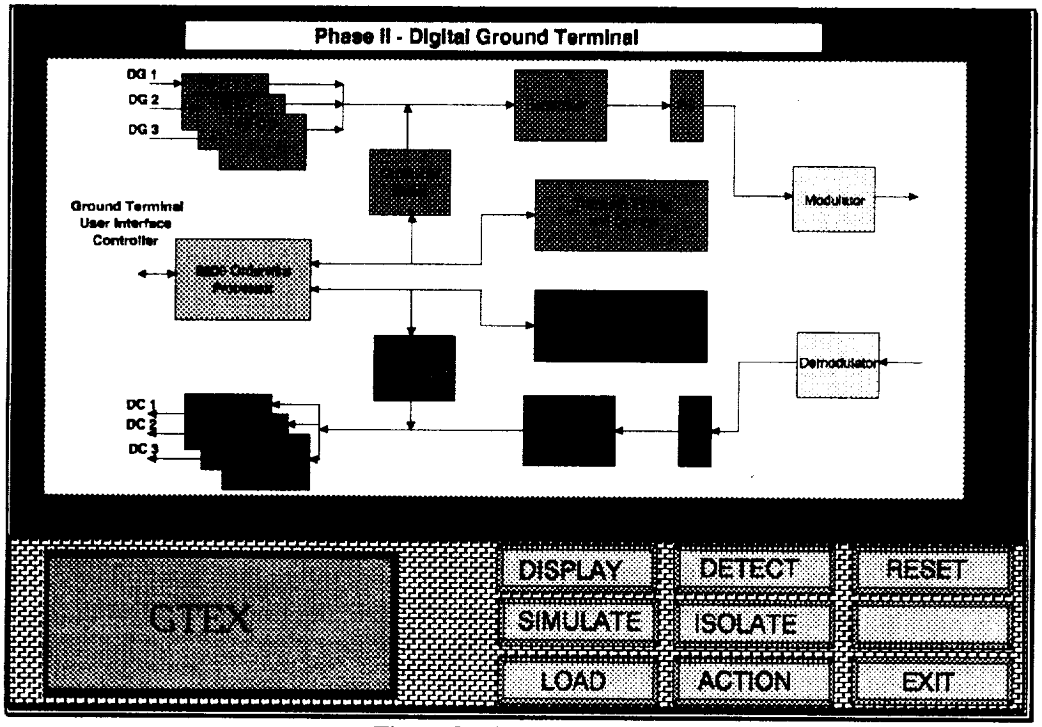

Figure 3 - GTEX Interface

The interface to GTEX was developed in C using the Essential Graphics Library developed by South Mountain Software. The modularity of the system was preserved by only employing 'C' constructs in development. A pseudo object-oriented architecture was constructed to simplify development of required displays.

5.2 Control Subsystem

Since the diagnostic procedures are being performed in cooperation with a technician, control of GTEX is necessary. Basic actions such as starting the diagnostic process, resetting the system and selecting the type of system dialog are originated by the control system.

Control of GTEX is performed by a function whose execution is controlled by ART-IM. The function, known as an asynchronous function, is called before the first rule-firing, between rule-firings and after the last rule-firing.

Developed using the Essential Graphics library, the control system responds to mouse interaction. Once interaction has been detected, validation tests are performed and proper procedures taken. The final result is the assertion of the corresponding fact into working memory. Control is immediately returned to the knowledge base if no interaction has occurred.

5.3 Query Subsystem

The end-user of GTEX has an option of two data input formats. A data file, simulating dynamic interaction with the SITE ground terminal is preferred. If data cannot be obtained from the data file, or at user request, GTEX will prompt the user for the required data.

The simulated data file is a ASCII text file with the following record format:

Object.Object-Property = Object-Value

Initilialization of the simulator is controlled by a message received from the knowledge base. The message received contains the name of the ASCII data file. The ASCII file is parsed and the corresponding object and properties are created and values inserted. Since the simulator objects mimic the objects associated with the knowledge base, the ART-IM schema notation is used.

To query a value, a message is received from the knowledge base denoting an object and the corresponding property of the value required. The inquiry begins by checking a status flag to decide if data is to be retrieved from the simulator. Found to be true, an object-property match is performed and corresponding data returned. Dialog is conducted with the end-user either when, a value is unavailable from the simulator or the status flag indicates that the end-user to be queried. During the dialog, the system halts execution until valid data has been obtained from the end-user.

5.4 Knowledge Base

GTEX performs the following tasks:

- Fault Detection
- Fault Isolation
- Fault Recovery Recommendation

The diagnostic procedure begins by determining the initial system configuration. Information is gathered about each data channel regarding the transmit, receive channels, and data rate. General information about the SITE ground terminal is also obtained. BER measurements are performed and evaluated on each of the user data channels to determine if tolerance limits have been exceeded. Once tolerance limits have been exceeded, the end-user is informed of the discrepancy and isolation of the fault begins.

Three levels of isolation are performed. The initial stage of isolation determines which side, transmit or receive, of the user channel is causing the error. Isolation is then performed to determine which of the corresponding subsystems is in error. Finally the corresponding circuit board is isolated. Once the fault has been isolated and end-user informed, GTEX can be requested to recommend a fault recovery recommendation

6.0 Knowledge Base Architecture

The knowledge base is divided into the following rule categories:

- Display rules
- Diagnostic rules
- Demon rules

Each rule category has its own salience or relative priority which is used in scheduling the rule for firing. This technique was implemented since the version of ART-IM used for development was unable to handle rule sets. Table 2 lists the salience values assigned to the individual categories.

Rule category	Salience
Display Rules	200
Demon rules	100
Diagnostic rules	0

Table 2 - Table of Rule Salience

6.1 Diagnostic Rules

The diagnostic rules are the foundation of the knowledge base. These rules perform the fundamental steps required in diagnosing the digital ground terminal. They are responsible for asserting facts into the working memory, which results in the execution of the detailed procedures, implemented using "demon rules" discussed in this paper, for the current level of diagnostics.

The diagnostic rules have the lowest priority of any rule group. This priority level is important in maintaining system integrity. The integrity is preserved by insuring that the diagnostic rules are reacting to current data. An example of a diagnostic rule is shown.

```
(DEFRULE Determine-Channel-Configurations
        (SCHEMA Ground-Terminal-Configuration
                (Attenuators-Connected YES|NO)
                (RF-Transponder-Connected NO))
=>
        (ASSERT (Determine Channel 1 Configuration))
        (ASSERT (Determine Channel 2 Configuration))
        (ASSERT (Determine Channel 3 Configuration)))
```

This rule assumes that the ground terminal configuration was perviously determined. The connection of attenuators and the RF-transponder with the digital ground terminal is checked. If the attenuator connection is known and the RF transponder found not connected, then facts regarding the user data channel configuration are asserted in working memory.

6.2 Demon Rules

Sitting dormant in the knowledge base are demon rules. The responsibility of the demon rules are to perform detailed diagnostic procedures. They are activated by the diagnostic rules which assert appropriate facts in working memory. The modification of objects is the primary procedure performed.

An example of a demon rule is shown.

```
(DEFRULE Determine-Channel-Configuration-Demon
    (DECLARE (SALIENCE ?*demon-salience*))
    (SCHEMA ?Channel
        (INSTANCE-OF User-Channel)
        (Channel-Number ?Number))
    ?demon <- (Determine Channel ?Number Configuration)
=>
    (MODIFY (SCHEMA ?Channel
        (Transmit-Channel
            =(SEND TX-Channel-Number User-Interface-Computer ?Number))
        (Receive-Channel
            =(SEND RX-Channel-Number User-Interface-Computer ?Number))
        (Data-Rate
            =(SEND Data-Rate User-Interface-Computer ?Number))))
    (RETRACT ?demon))
```

For each instance of a user channel in working memory, the rule fires which modifies the object after obtaining the data desired. The data in this case is the transmit and receive channels associated with this data channel and the corresponding data rate. Actual data values are obtained by sending a message to the appropriate object.

6.3 Display Rules

Display rules are responsible for setting and updating the display based on schema values in the knowledge base. They are also responsible for intercepting and processing fact messages from the control system. Rules regarding display have the highest priority to ensure that the display is always updated. An example of a display rule is shown below.

```
(DEFRULE Select-User-Dialog
    (DECLARE (SALIENCE ?*display-salience*))
    ?display-fact <- (ACTION SELECT USER-DIALOG)
=>
    (BIND ?*simulator* (send-message display-system "dialog simulator"))
    (send-message display-system "message 102")
    (retract ?display-fact))
```

This rule shows a fact message from the control system which informs the knowledge base that the end-user wants to select the type of user-dialog. The right-hand side of the rule then sends two messages to the display system.

7.0 Summary

As more emphasis is placed on developing low-cost efficient ground terminals, expert system technology will play an essential role. GTEX is being developed as a prototype, demonstrates the ability of expert systems to provide needed assistance in ground terminal operation. The modular approach taken will allow GTEX to adapt to new system designs. Adhering to this viewpoint, future consideration includes modifying GTEX to enhance the capabilities of the High-Burst Rate Link Evaluation Terminal (HBR-LET) designed for the Advanced Communications Technology Satellite (ACTS) Project at the NASA Lewis Research Center.

8.0 Acknowledgments

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